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Epitrochoid Power-Law Nozzle Rapid Prototype Build/Test Project

Mr. Eric J. Paulson-Vehicle Analyst

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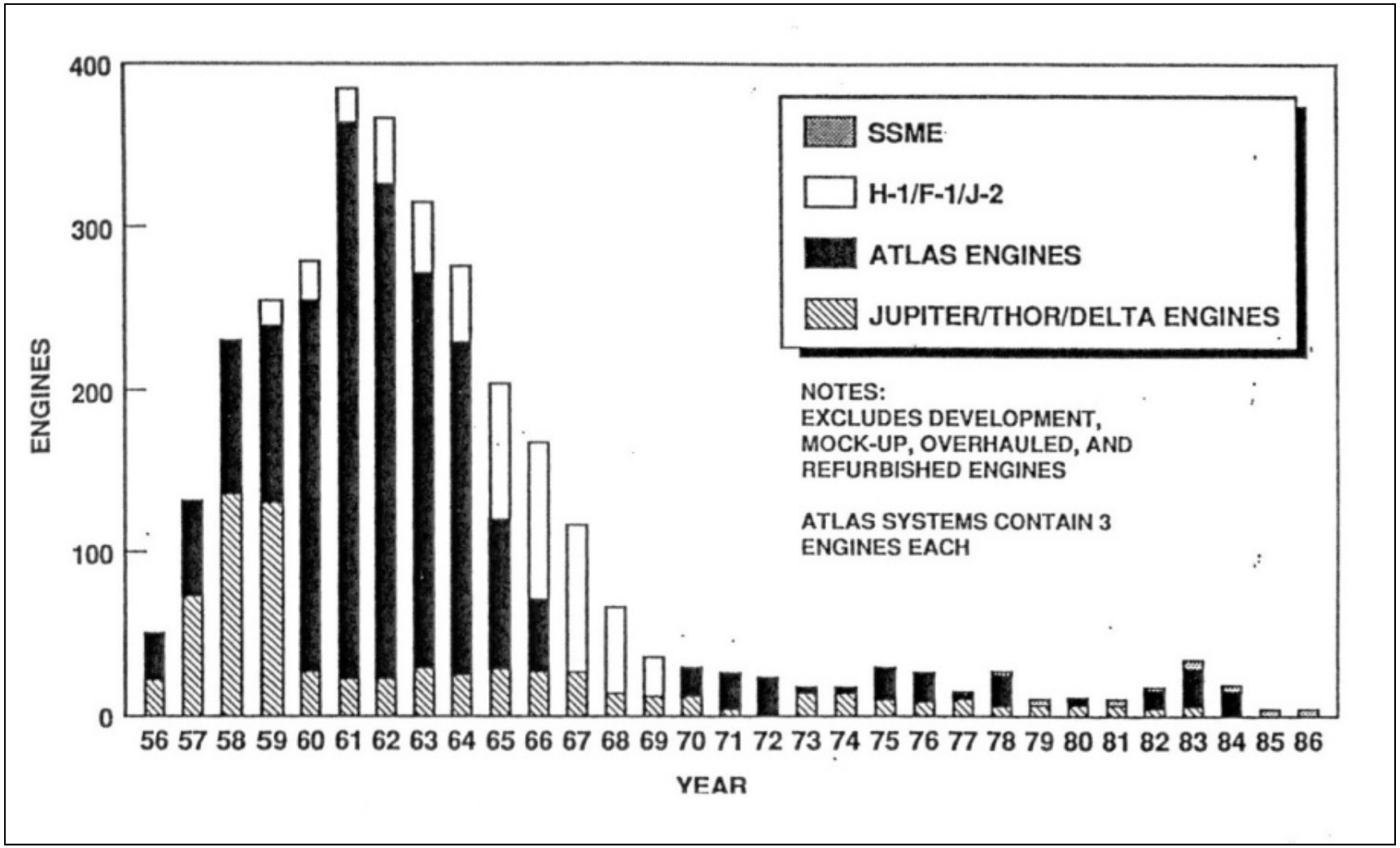
Combustion devices Branch

Systems Analysis Group

Epitrochoid Power-Law Nozzle Build/Test
Overview

- **Who**:
  - **PM: Eric Paulson RQRC Systems Analysis Group**
  - **Partners: Dr. Shelley, Lancaster University Center**
- **What**: **6-month Rapid Prototype Build/Test N_2 cold flow prototype of Epitrochoid Power-law Nozzle (EPN)**
- **Where**: **Lancaster University Center (LUC)**
- **Why**:
  - **Demo initial proof of concept for new 3D multiple plume nozzle**
  - **Demo new cold flow nozzle manufacture/test approach**
- **Cost**: **To Be Determined (TBD)**

Economics of Decreasing Annual Rocket Engine Production



Epitrochoid Power-Law Nozzle Build/Test
Build on SpaceX Multiengine Approach

Engines: Merlin 1D on Falcon 9 v1.1 (Photo SpaceX)

Epitrochoid Power-Law Nozzle Build/Test
Under-to-over expansion of Multiple Plumes

- **Falcon 9 launch video here**

Epitrochoid Power-Law Nozzle Build/Test
A Type of Radially Lobed Nozzle

Lobed Nozzle Extension for Better Gas Dynamic Incorporation of Modular Thrust Cells Exhaust

- **Implementation Requires a Parametric Design of Lobed Shape**
- **Epitrochoid Planar Curve Fits the Bill**

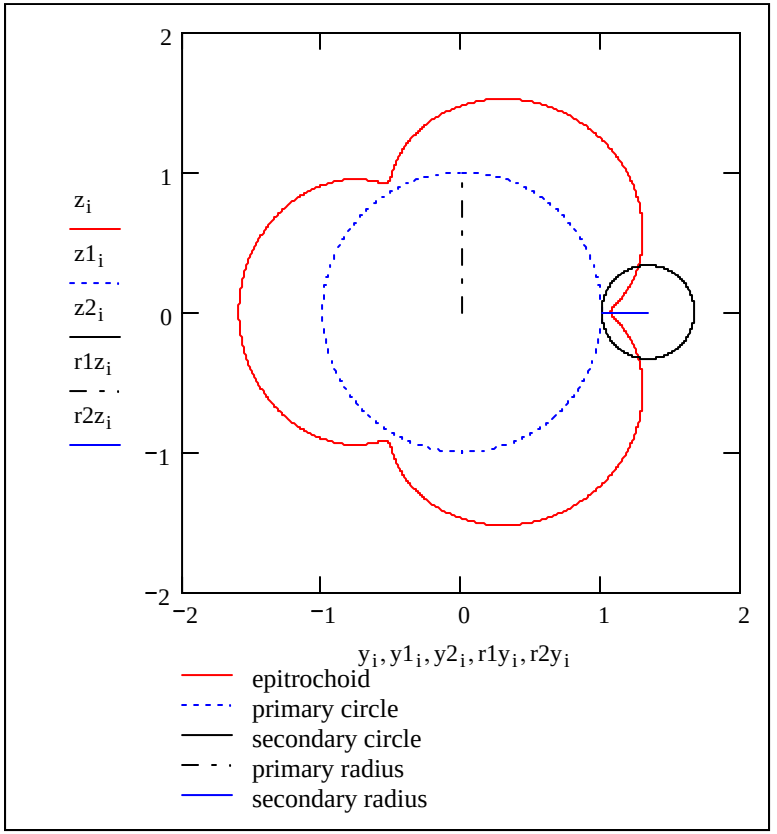
<u>Parameterized by R1, R2, k, and d</u>

R1: primary circle radius

R2: secondary circle radius

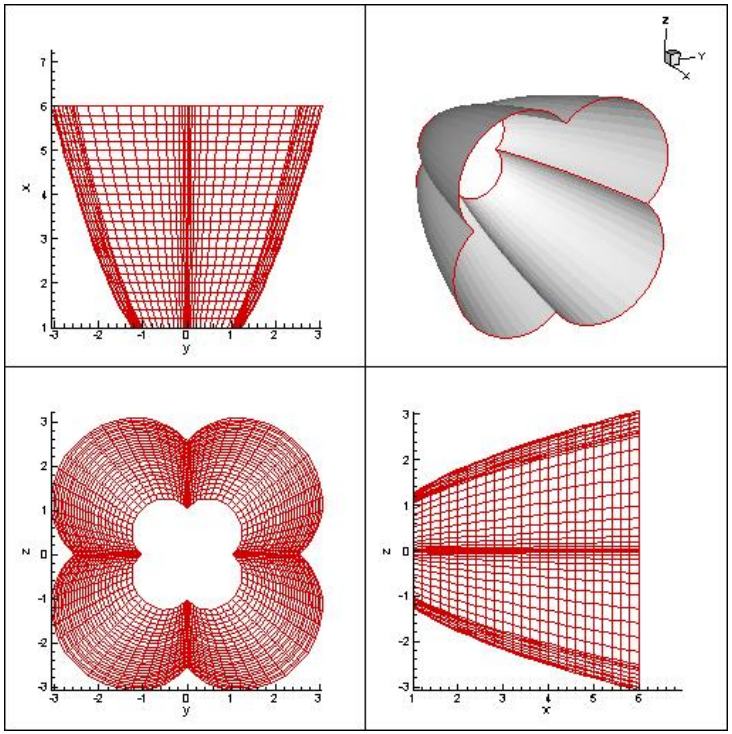
k: ratio of R1/R2

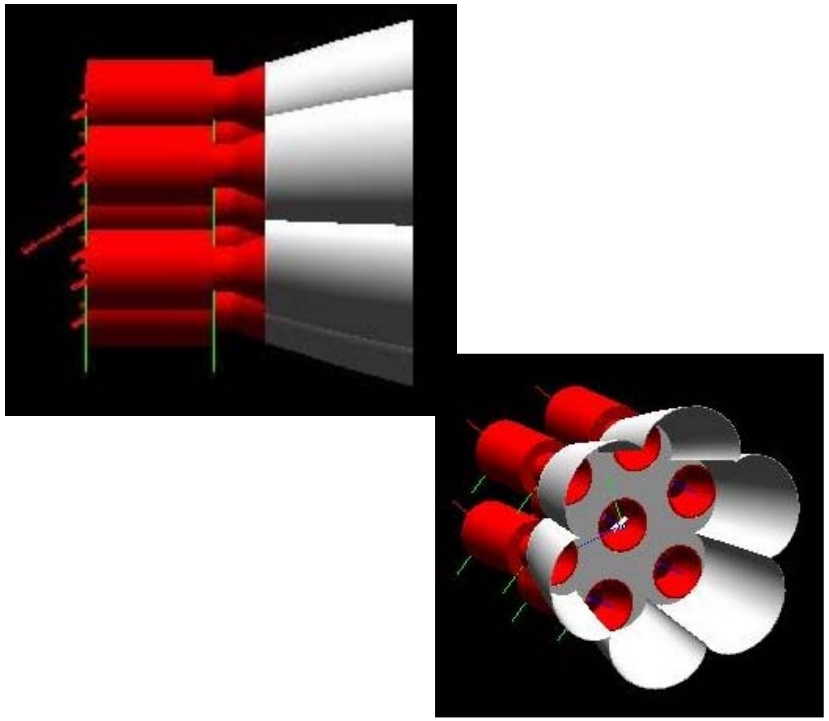
d: normalized generating parameter



Epitrochoid Power-Law Nozzle Build/Test
Nozzle Extension Surface Definition

A power-law relationship for R1 primary circle radius as function of x defines a semi-infinite surface from x=0 plane. Adding x_{min} & x_{max} bounds creates a diverging radially lobed nozzle extension shape.





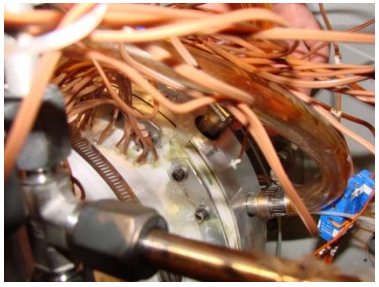
Typical Nozzle Test Article Costs

- **Multiple nozzle cold-flow testing using traditional manufacture would be prohibitive**
  - **Typically 1-3 test articles tested over 8 week test period in cold-flow facility**
  - **Currently: $30-100k manufacturing cost per <u>metallic</u> test nozzle depending on complexity**
  - **$30k for mechanical design of test article**
- **NASA-MSFC Rapid Prototyping Demo costs: $3-5K for in-house manufacture & process development, per nozzle**

Manufacturing cost reduction of 90-95% per nozzle test article

NASA-MSFC Lessons
New Material Requires New Design Approach

- **Weaker than metal**
  - **distribute flange loads**
- **Thermal insulator instead of conductor**
  - **account for thermal gradients**
- **Avoid multipart designs with lots seals:**
  - **build in the passages**
  - **“Cartridge” test article and housing**



Takeaway Questions
Objectives

- **Objectives**
  - **Develop extremely cheap and fast method to build experimental test nozzles**
  - **Develop extremely cheap and fast test rig to bench-level sea-level cold flow test**
  - **Develop cheap/fast method to build lobed Epitrochoid Power-law (EP) nozzle extension**
  - **Demo proof-of-concept cold flow testing of the EP nozzle**

Takeaway Questions
Why is This Innovative

- **Some related work occurring in industry: <u>metallic</u> additive mfgr demoed/used for small thrust cells, propellant injectors and valve housings**
- **Cold flow nozzles are being built same way as they were in 1960.**
  - **EP nozzle: a new way to utilize features of high performance engines advances and the economies of scale of the multi-engine approach of SpaceX Falcon 9**
  - **Rapid Prototype cold flow testing:**
    - **Enable order-of-magnitude cost reduction for build**
    - **Enable extremely rapid, affordable design exploration for 3D classes of nozzles**

Takeaway Questions
What is Success?

- **Lots of off ramps to declare success**
  - **Feasible new quick/cheap cold flow test design approach (criteria=better than current approach with usable wall pressure data)**
  - **Feasible to build axisymmetric cold flow nozzle test articles using plastic-based inexpensive rapid additive manufacturing**
  - **Feasible to rapid prototype lobed nozzle extension**
  - **Feasible lobed nozzle extension**
    - **Criteria=demo proof-of-concept for stable full-flowing lobed nozzle at sea level**

Why Choose to Work This Project?

- Fame, glory, and the accolades of your peers…
- Opportunity to legitimately call yourself a rocket engineer
- Chance to work on something cutting edge
  - No other teams in US working on low cost cold-flow test nozzle designs currently
  - The lobed epitrochoid power-law nozzle concept is new and original: you're looking at the inventor
- Opportunity to publish/present the initial results for what may continue into a bigger program